Research Synopsis for Pre-Ph.D. Seminar

Implications of Urbanisation on the Water Resources in a Planned Urban Landscape: A Case Study of New Town, North 24 Parganas, West Bengal

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Implications of Urbanisation on the Water Resources in a Planned Urban Landscape: A Case Study of New Town, North 24 Parganas, West Bengal

Urbanisation is one the prime driving forces of the anthropocene. With urbanisation blossoming in the developing world, water "wants" are increasingly straining the available resource and increasing its depletion. This is further aggravated by the development of self sufficient "smart townships". Such a situation is the reality of New Town, North 24 Parganas West Bengal, where without prior consideration of water provision, a future smart township is being built. Home to rapidly growing gated population, this locale is perhaps the highest water intensive zone amongst all satellite townships in West Bengal. Yet there exists no proficient fresh water source other than the aquifers. Increasing real estate growth has further triggered groundwater depletion in the aquifers are their waters are primarily turbid and replete in salts as a result of over-extraction. Aggravating this condition, built-up surfaces have prevented recharge, increased the both land surface temperatures and evapo-transpiration rates. Urbanisation trends have swallowed more than 80% of the natural water-bodies and the few that remain are either marginally used, left derelict or are used as disposal sites near the 'rurban' patches. As a solution, water needs of citizens are met by siphoning water from the Hooghly river and treated in bulk amounts to meet the high consumption rates, making household water very costly, notwithstanding its un-palatability in places. In addition to these, unlike smart township characteristics, emergency water supplies are practically non-existent. Conversely, there is a step motherly attitude towards water provision for the village population, residing within the boundaries of the township. They access water from tube-wells nearby, submersibles at residences, or even buy water. Thus, unsustainable water use within New Town has a wider negative influence on distant water reserves. Hence, to improve the present situation, this thesis shall make an attempt to assess the hydro-geological condition vis-a-vis present water woes and emphasize upon sustainable alternative sources of water supply and pave a smoother path towards creating a green/smart city.

Keywords: urbanisation; depletion; water resources, hydrogeology, sustainable.

1. Introduction

Water is the world's most unique resource. It is perhaps the only finite element which is essential for the health and prosperity of human beings and his immediate biotic surroundings. Provision of adequate safe potable water reduces the vulnerability of the human's from disease and thus enhances the productivity of human society and the environment. But unfortunately man's water wants have been such that the resource and its quantities have begun dwindling. Water is only renewable if it is well managed. Considering the available surface and groundwater resources, pressures of urbanisation and agricultural activities in rural areas and their individual water demands are continuously rising. Therefore, the need of the hour is to reduce wastage to a bare minimum and preserve water in such a manner that distribution and use do not pollute or deplete the resource. This allows optimum management, use and preservation of water resources.

2. Literature review:

Urban or being 'urbane' has many connotations. In India, the Census considers urban areas to have a population of more than 5000, a population density of around 400 persons per square kilometre with seventy-five per cent non agricultural persons residing in a region governed by a "municipality", a "corporation", a "cantonment board" or a "notified town area

committee" (Census of India, 2011). Finite land spaces make increasing urbanisation convert land use and land cover, replacing it by built-up surfaces. Thus, alike previous literature, Land-use and land cover change (LULC) has been used in this research as the main indicator of urbanisation. With time these 'urbanscapes' become a highly dense network of human living spaces, expanding due to increasing number of urban inhabitants, increasing earnings, and declining travelling expenses in congested urban spaces (Brueckner, 2000). But this in turn adversely affects the water-bodies by forcing its decline in area as well as quality over time (Dewan & Yamaguchi, 2009; Du, Ottens and Sliuzas, 2008).

In Whittington's 1987 work "A Study of Water Vending and Willingness to Pay for Water in Onitsha, Nigeria," he suggests that to check the extravagant water uses, water metering and water pricing is required, one which should be selected after studying household behaviour in case of securing water for domestic or household purposes prior to fixing water costs. But in his work he has not considered the ethical, cultural and social values as tools for reducing water demands among different groups of people. For New Town therefore, compartmentalising of these aspects shall not be done and shall be integrated as a tool for preserving the available water sources.

Population increase adversely affects the water supplies. As a result, population projections need to be contrasted with water supplies to create sustainable cities which do not invite water crisis (Engelman and LeRoy, 1993; Zahra, 2001; Sun et al. 2008; Bruggen, Borghgraef & Vinckier, 2010 ;Mukherjee and Chakraborty, 2016). Urban areas need a reliable, regular supply of treated water for conducting its allied activities as a delay in water supply or a deficit in allocation can be a vital deterrent for healthy urban life (Cairncross, 1990; Howe et al., 1994; Zhou, 2002; Purohit, 2015).

In the face of changing urbanisation trends and atmospheric processes the groundwater has been severely affected. Such has been depicted in the extensive literature which talks of urbanisation and its impacts on groundwater, for example the works of Foster, Morris and Lawrence (1994), Harbor(1994), Zilberbrand, Rosenthal & Shachnai, (2001) Duque, Chambel and Madeira (2002), Jiao, Wang and Nandy (2006), Naik et al. (2008), Sharp (2010), Chang (2010), Del Campo et al. (2014), where the negative effects of urbanisation on groundwater have been expressed, i.e., decline of water levels, lack of recharge, increase of urban runoff in places like Hong Kong (China), Solapur (India), Tel Aviv (Israel), Toluca Valley (Mexico) etc.

C. Ramachandraiah and Sheela Prasad (2004) in their article *Impact of Urban Growth on Water Bodies The Case of Hyderabad,* have made land use change and surface water pollution two interrelated subjects. This is true in the case of New Town too since decreasing natural land cover is proportional to deteriorating surface water qualities. Thus implementing this through remotely sensed band math calculations helps make an accurate estimate of changes, some of which have been devised via indices like the Built-up Index (BI), index based built-up index (IBI), Enhanced Built-up and Bareness Index (EBBI), New Built-up Index (NBI), Normalised Difference Built-up Index (NDBI), Normalised Difference Vegetation Index (NDBI) Enhanced Normalised Difference Impervious Surfaces Index (ENDISI), Normalised Difference Water Index (NDWI), Modified Normalised Difference Water Index (MNDWI), Automated Water Extraction Index (AWEI), Fisher's Water Index (WI) and many others which adequately help to compare urbanisation trends and water-body changes(Chen et al., 2006; Zhang, Odeh & Han, 2009; Liu, Liu, Zou 2009; Xiong et al., 2012, Mitra &Banerji, 2018; Al-Bilbisi, 2019).

The current anthropocene has an all pervading effect and has even affected the land surface temperature (LST), precipitation, as well as the evapo-transpiration(ET) rates. Innumerable articles have depicted that urbanisation does adversely affect the meteorological and hydrological characteristics of any growing townscape (DeFries and Eshleman,2004;

Khandelwal and Goyal, 2010; Zaharia, 2016; Wakode et al. 2018). Increasing surface temperatures may lead to excess warm layers of air and this might lead to the decrease in the amount of precipitation and even reduce the total amount of evapo-transpiration. So these two aspects have been considered to be an integral part of the hydrological regime of the land.

Fayyaz A. Memon and David Butler (2005) have stated in their article, *Gray Water Reuse in Households* that population growth and consumptive water usage go hand in hand. Therefore, to curtail escalating demands of water, re-use of grey or gray water may fulfil all those activities which do not require potable water applications. This method has been envisaged for the study area, New Town, such that re-use infrastructure may be implemented to reduce the burden on potable water for all water intensive activities

Access to safe drinking water being a human right needs to be implemented. But with population pressure treatment services are unable to provide equitable distribution of safe drinking water (Khatri, Vairavamoorthy & Porto, 2008;Duh et al. 2008; Narain, 2014). Since many of the denizens drink raw water without purification right from the accessible points it is essential to understand the quality of groundwater and other surface water resources within the present study area.

Abdulla, F. A. and Al-Shareef, A. in 2009, depicted in their research paper, *Roof rainwater harvesting systems for household water supply in Jordan*, that collecting the rainwater from roads, parking lots and rooftops can help to supplement 5.6per cent of water required for domestic purposes and help to reduce escalating demands for water. Such a motive, if utilised in New Town, will help in the development of new strategies for sustaining the water needs of the township in future.

A.Y. Chapagain and Tickner (2012) in their working paper named *Water footprint: Help or hindrance?* have said that fresh water supply through surface as well as groundwater reserves cannot always meet the wants of people. If the current trends of population growth goes on it is estimated that the 'world will face a 40 % shortfall between forecast demand and available supply of water by 2030'. But theoretically defining the shortfall is difficult, and the best way to assess this is to calculate the water footprints of individuals or families.

The Ministerial body, also known as the Central Public Health and Environmental Engineering Organization (CPHEEO) (2013) in their report named "Advisory On Conservation and Restoration of Water Bodies in Urban Areas" have stated that lakes and urban water bodies are an intrinsic part of the urban landscape, collecting rainfall, recharging the groundwater and supporting a huge variety of flora and fauna. Therefore they need to be protected and preserved and created if required to maintain a healthy ecosystem. This is one of the most neglected issues in New Town. Water bodies are almost close to vanishing thereby increasing flooding tendencies and recharge problems. Thus water body revitalisation shall be one of the key points of focus in this research work.

Metropolitan areas cannot be deficit in adequate water infrastructures and must also have an extensive reach as decentralised urbanisation trends often engulf peri-urban areas for their needs (Srinivasan et al. 2013; McDonald et al., 2014). As a result, often it is found that the urban poor reside in low cost peri-urban areas in the hope of availing access to clean drinking water (Satpathy, 2014). This excess pressure leads to increase in water prices which is not a sustainable aspect of urban water systems. Therefore, it is imperative to have an affordable but adaptive urban water infrastructure to meet these problems.

Gogana Venkateswarlu, G Jayasankar, B.V. Saradhi (2014) in their research paper *Impact Assessment of Land Use Change on Ground Water Quality Using Remote Sensing and GIS for Zone V under Municipal Corporation Hyderabad* have stated that with a change in land use leads to pollution of ground water, a result which has been analysed by water

sample collection and Water Quality Index (WQI) equations through the GIS platform. But which parameters dominate the water characteristics or which parameter exists at a greater proportion than others has not been analysed. Since New Town has the disadvantage of being close to the Barasat Arsenic belt, WQIs its spatial interpretation through ArcInfo as well as statistical interpretations from the chemical tests shall be provided to analyse which parameter has adversely affected the quality of water. This shall provide a clear understanding about the hydrochemical conditions of groundwater.

In the World Water Week, the United Nations General Assembly, under Resolution 64/292 in 2015, has declared that access to clean water is a human right. This acts as a measure which would prevent misuse of water and enforce equitable distribution. But this has not been enacted in its true form in the study area.

As per the World Water Assessment Programme (WWAP) in The United Nations World Water Development Report 2015: Water for a Sustainable World report in 2015, the world experiences 4°Celsius warmer temperatures and monsoon deficits each year, making water protection and water security strategies imperative. Therefore the need of the hour today is the creation, protection and preservation of newer or pre-existing water sources so as to reduce water stress in areas around the world. But in the report ways and means to predict water stress has not been mentioned. Hence for the present research, Water Stress conditions have been studied considering the available resource and the dependent population so as to adequately improve the situation within the study area.

D. Chakraborty in a news paper article to the Statesman (30th April 2016), states that India's annual water availability is dwindling. As per the Central Water Commission estimates, the available fresh water has decreased from 1816 cubic metres per capita in 2001-02 to about 1544 cubic metres per capita in 2011 and is apprehended that this might further reduce to 1140 cubic metres by 2050. Yet large scale water harvesting schemes, grey water re-use infrastructure do not exist pan India. Being a developing township, New Town has the potential to supplement a large percentage of people's water requirements if it can effectively tap the rainwater and untapped domestic grey water.

Manas Das (2016), one of *The Statesman*'s investigative journalists have found out, that there is a direct relationship between wetland reduction and water table fall. According to him, the massive reclamation of water bodies in the Eastern Fringes of Kolkata, more precisely New Town areas has led to a fall in the ground water table over the years. Escalating population growth has led to excessive groundwater extraction rates. Tarmacked surfaces and more built up areas have decreased infiltration rates, thereby lowering the static and piezometric water levels (SWL and PWL). But in spite of rising population trends the township has not yet taken up the challenge for harvesting both used water and freshwater from the rains for optimum water use.

Hence, if water body creation and revitalisation, rainwater and runoff harvesting grey water recycling and water demand reduction is attempted, along with adequate use of water metering, etc. not just the present generation but the future generation will also be able to tap the required amounts of water without suffering from the existing water woes in New Town.

3. Research Gap and Uniqueness of the Present Endeavour:

Till date, research work conducted in the field of urbanisation and water resources has not tried to relate physiological with social factors to create a sustainable water solutions for urban areas. There are very few articles which have been written about New Town and none of them talk of the water supply and management system in the study area. Published articles, books, reports, journals and newspaper articles accessed for this purpose, suggest that even after 18 years of its establishment, it is the urban growth which needs to be paid attention. Its

increase in size and its role as a catalyst in the development of more satellite townships has received appraisal till date.

Further, there is no consideration about its water stress, distance from major water supply resource or increasing deterioration in water quality and its distribution costs. Yet in future it has to metamorphose into a smart green city with perfect living conditions.

4. Study area

New Town(Rajarhat) is a newly developing urban area existing to the north eastern fringes of Kolkata, which lies exactly to the north of Salt Lake City, commonly also known as the Bidhannagar Municipal Corporation, precisely within 22^0 33'N to 22^0 37'N latitudes and 88^0 27'E to 88^0 32'E longitudes (Figure 1).

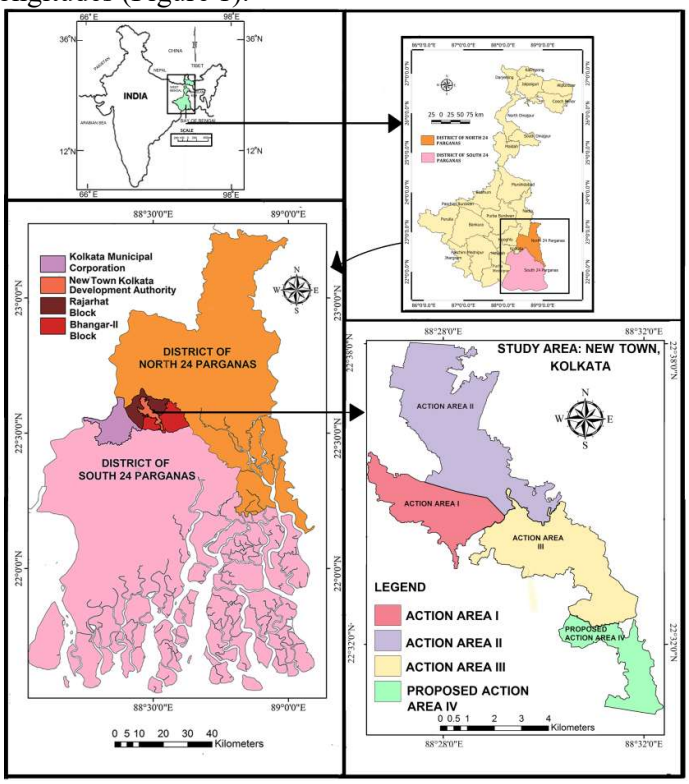

Figure 1: Study Area of New Town(Rajarhat), West Bengal

Other than Salt Lake City, New Town(Rajarhat) is another satellite township which has been developed to reduce the burden on the metropolis in every sphere. Developed under the leadership of the then Chief Minister of West Bengal Buddhadeb Bhattacharya in the late 1990s, New Town(Rajarhat) was envisaged to be at least three times bigger than Salt Lake City and was designed to provide site and services for 87 thousand people, for whom a shelter area of about 736 acres was assigned (CMDA and Housing Directorate, 1982). This area was not only supposed to provide shelter but was developed to give employment to all sections of people, particularly the economically weaker sections of the populace; provide adequate infrastructure services (water supply, drainage, roads, pathways and community facilities) and serve as an area for industrial development (CMDA and Housing Directorate, 1982).

New Town(Rajarhat), is a growing urban landscape today, comprising of large residential complexes, educational institutes and commercial enclaves. Each of these has extravagant water demands, which exert pressure on the water available. Yet it takes the

available water resource for granted. Negligible conservation or preservation procedures are active here in spite of the expensive water supply procedure, water disparities, and improper potable water quality. Unlike other newly developing townships, New Town is still in the formative stage and has the potential for developing water conservation infrastructures and supplement the existing water supply with rainwater harvesting and grey water recycling systems. Thus, this township acts as a case study for this research work, so that evaluation of the available water resources vis a vis urbanisation trends may not only help this soon-to-be smart city, but similar urban spaces at the same time, to develop a successful pro-water urban infrastructure for the advantage of its citizens.

5. Statement of the problem

New Town(Rajarhat) was a foreseen future, considering the degree of urban growth that might take place, post 2001, i.e., after its initiation. With such a plan in mind, Action Areas I, II and III were established with a new CBD, where the congestion of administrative duties could be diverted. But New Town(Rajarhat), unlike Kolkata which did not have a proficient freshwater source within its boundaries, was supplied with a mixture of surface and groundwater, the former drawn from the Hooghly while the latter was taken from the underground aquifers, to sustain the daily demand of people. This withdrawal of water led to drastic piezometric fall, increasing the presence of salts and pollutants in groundwater. Presently, with a population of above 60,000, the administration of New Town(Rajarhat)- the New Town Kolkata Development Authority(NKDA) depends completely on the waters from River Hooghly just to face a plethora of new problems. Being a costly supply of potable water, treated water pipelines are active in Action Areas I, II and partially in Action Areas III. Tax is charged for this water without a uniform water metering system, and only the taxpaying citizens receive the treated water. Action Area IV is an unplanned urban outgrowth, devoid of water distribution lines and utilises only groundwater, in spite of being majorly unpalatable. Residents of Action Areas I, II and III occupy around 40% of New Town(Rajarhat) project area and require a total of 10 MGD of treated water, wherein 135 litres per capita daily (lpcd) is sent to the households. But treating such an amount of water is a costly affair and many a time potable water quality keeps deteriorating. Once the huge expanse of the township is optimally populated, a 24x7 supply of 135 lpcd of water, might even induce water shortages, escalate future water prices, and increase impurities and become a vital deterrent to equal distribution of water. This would adversely affect not only the gated communities but even the economically weaker sections.

Thus considering these problems an efficient system has to exist such that both present as well as future needs of water could be adequately met without negatively affecting the environment

6. Objectives:

a. Assess the land-use change caused by urbanisation and detect changes over time to study the reducing expanse of surface water with relation to the growth of built up area.
b. Analyse the temporal change of groundwater before and after the development of New Town(Rajarhat), with the help of secondary data on groundwater levels such that the piezometric level of groundwater may be equated with trends in population growth and urbanisation.

c. Analyse the existing water supply system and cost effectiveness of the distribution network vis a vis a growing population, so that the supply side equity may be maintained.
d. Study the quality of water used by the households for drinking and other daily requirements once supplied by the municipality,
e. Estimate the consumptive water usage, and suggest measures for a sustainable use of the existing water resources with special emphasis on rainwater harvesting and grey water recycling.

7. Database and Methodology

7.1. Database:

The present research delves on the effect of urbanisation on the water resources. Database used in this regard include accession of cloud-free Landsat 5 and 8 imageries from the USGS Earth Explorer website, piezometric water level data from the Central Groundwater Year Book published by the Central Ground Water Board (CGWB) and official lithological records from West Bengal Housing Infrastructure Development Corporation (WBHIDCO). Details of the existing population were consequently retrieved from the New Town(Rajarhat) Kolkata Development Authority (NKDA) office. Following this the EarthDATA website was used to study the hydrological regime of the area during and after its inception. The data used were the MODIS 11B3 Terra Land Surface Temperature/ Emmissivity Monthly L3 Global 6km SIN Grid V006 imageries for depicting the Land Surface Temperature (LST), MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500m SIN Grid V006 for estimating evapotranspiration rates and Monthly Rainfall 3B43 V6 Tropical Rainfall Measuring Mission (TRMM) data, to identify how the three attributes change over time.

Other than these secondary data, there exists two types of primary data in this research work, the first one being the random collection of water samples from the various available water resources, while the second one is the responses collected from gated and non-gated groups of individuals within New Town(Rajarhat) through questionnaire surveys. Applying the networked sampling method for the response recording, individual family sizes, income and age groups and individual preferences regarding the existing water supply situation within the study area, have been gathered to aid in the assessment of the effect of available water on society and vice versa.

7.2 Methodology:

7.2.1. Land-Use Land Cover change and Water-body dynamism:

7.2.1.1 Methodology:

The Land-use and Land Cover (LULC) change, as a consequence of urbanisation, within the study area is highly diverse. Attune to the changes and increasing land-use conversion tendencies of real estate businessmen, the water-bodies have been subject to rampant water-body decline. Pre-processed cloud-free Landsat 5 and 8 images in QGIS 3.4.2 were subjected to the supervised classification technique and raster files were created at 86% kappa accuracy. These along with the band ratios such as Enhanced Normalised Difference Impervious Surfaces Index (ENDISI) and Fisher's Water Index(WI) was used to depict the perceivable LULC changes. The band ratios utilise the following equations (Fisher, 2016;

Chen et al., 2019):

$$MNDWI = (\rho Green - \rho SWIR1)/(\rho Green + \rho SWIR1) \quad (1)$$

$$\alpha = (2 \times \rho Blue)_{Mean}/\{(\rho SWIR1/\rho SWIR1)_{Mean}/[(MNDWI)^2]_{Mean}\} \quad (2)$$

$$ENDISI = \frac{[\rho \mathbf{Blue} - \alpha \times \{(\rho SWIR / \rho SWIR1) + (MNDWI)2\}]}{[\rho \mathbf{Blue} + \alpha \times \{(\rho SWIR / \rho SWIR) + (MNDWI)2\}]} \quad (3)$$

$$\text{Water Index(WI)} = 1.7204 + (171 \times GREEN) + (3 \times RED) - (70 \times NIR) - (45 \times SWIR1) - (71 \times SWIR2) \quad (4)$$

Using a 9 year interval since the commencement of construction in New Town(Rajarhat), the chronological changes of land-use land cover have been portrayed. Further, to understand whether urbanisation and water body reclamation has led to homogeneous or heterogeneous landscapes devoid of most water-bodies the Land-Use Mix(LUM) index vis-a-vis water-body areal reduction scenarios have also been traced using the following equation:

$$\mathbf{LANDMIX} = -\frac{\sum i1n \left(Pi * (\ln Pi)\right)}{\ln n} \quad (5)$$

7.2.1.2 Results and Discussion:

The results from the change detection maps depict that over the years urban spaces have increased greatly(Figure 2, 3, 4). If the maps are traced from the time when the inception of New Town(Rajarhat) had not happened, till the present day, it is evident that water bodies have been replaced by high rise buildings or plots.

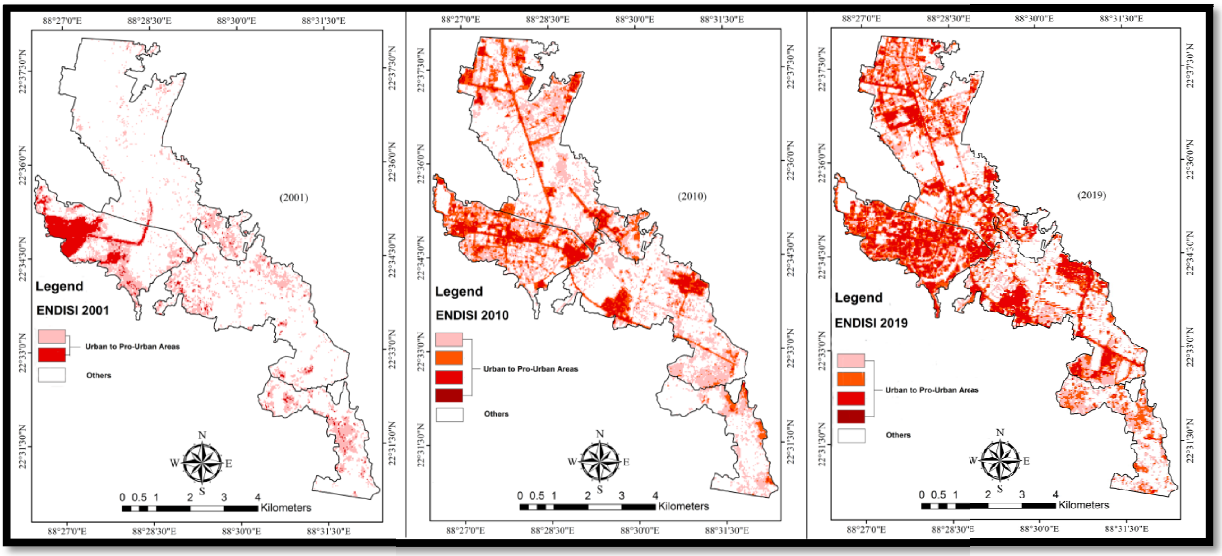

Figure 2: Enhanced Normalised Difference Impervious Surfaces Index (ENDISI) map for New Town(Rajarhat); Source: Landsat 5 and 8

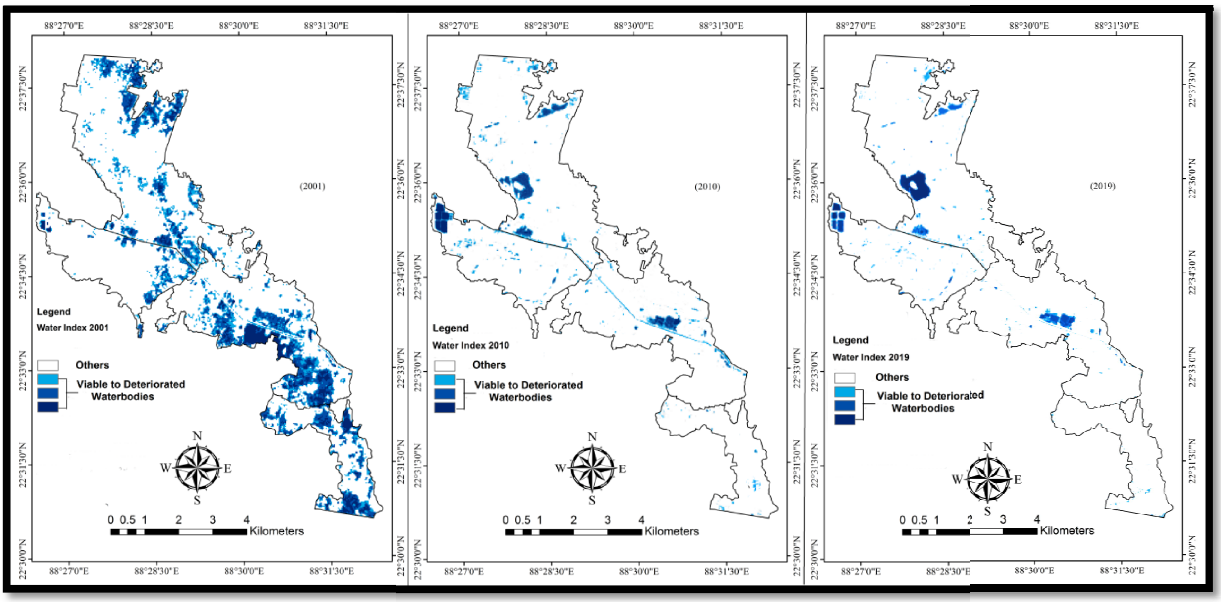

Figure 3: Water Index Map of New Town(Rajarhat); Source: Landsat 5 and 8

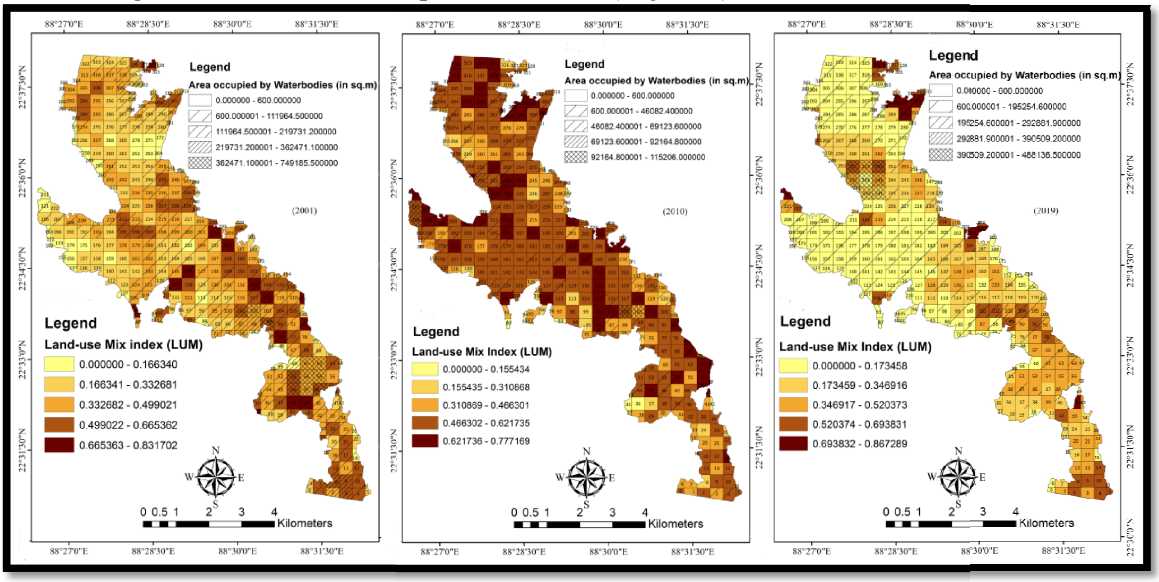

Figure 4: Land-use Mix Index and areal coverage of Waterbody; Source: Landsat 5 and 8

Their areal expanse has decreased whereas the areal expanse of urban plots have increased. This fact is emphasized when Land use Mix assessment is conducted on the available Landsat values. It is seen that in majority instances wherever the land use heterogeneity has increased, the areal coverage of water bodies have decreased in number. This is because as the intensity of land use categories in a particular grid increases, more area is occupied by land use and the original land cover is adversely affected. This is further validated by the ENDISI and the WI where band ratios applied on satellite imageries depict the radical decline of surface water bodies. Temporally, since 2001, 2010 and 2019 the LUM ranges from 0.15 to 0.83, 0.15 to 0.77, and 0.15 to 0.87, respectively. On the other hand, the areal occupancy of water bodies changes from 600-7,50,000 sq.m, 600-1,15,000 sq.m, to around 600-4,90,000 sq.m by 2019.

7.2.2. Assessment of the temporal change of groundwater before and after the development of New Town(Rajarhat):

7.2.2.1 Methodology:

Evaluating how urbanisation has had an over-bearing impact on the hydrological and groundwater attributes of the "urbanscape", Land Surface temperature(LST), Evapo-transpiration(ET) and Rainfall data/values were extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) missions such as 11B3, MODIS mission 16A2, and Tropical Rainfall Measuring Mission (TRMM) 3B43 series, respectively, after which they were contrasted with the piezometric data provided by the Central Groundwater Board (CGWB). The TRMM files were further converted from rainfall rates to rainfall measured in millimetres. The average of all the meteorological data was extracted and calculated followed by mapping in the Surfer 15 software.

Following this, the changes in the secondary piezometric water level (PWL) data, their rises and falls and its relationship with annual average rainfall for Tropical Rainfall Measuring Mission (TRMM) has been related in the Surfer 13 software. Decadal rises and falls in piezometric level have also been represented through the Krigging technique in Surfer 15. Subsequently, since often altered soil layers have a tendency to affect infiltration, such a study has been further utilised here and its taxonomy has been represented through the Rockworks software, to depict whether the soil inhibits infiltration or not.

7.2.2.2 Results and Discussion:

Land use intensities are increasing over the years it is probable that the Land surface temperatures may also increase due to the effect of cemented and tarmacked surfaces.

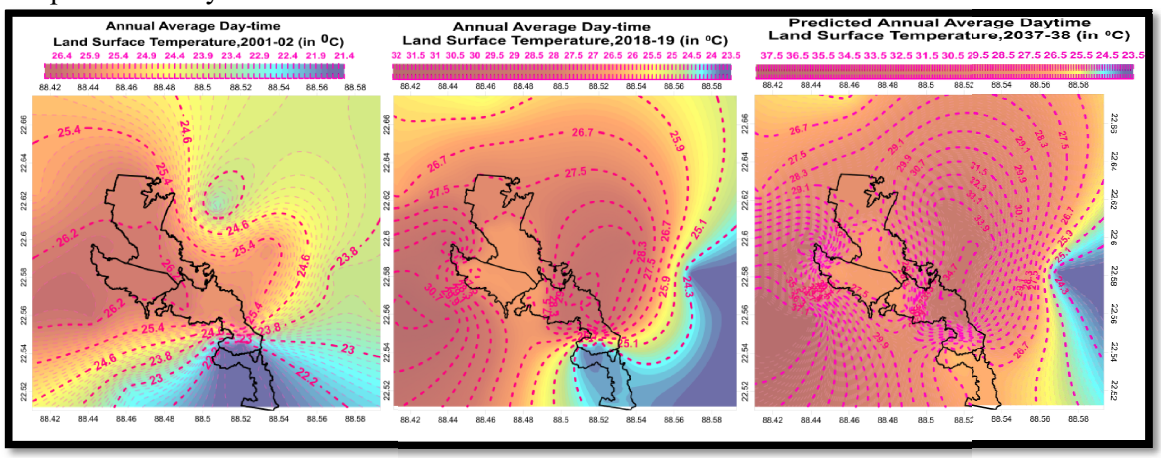
Annual Average Day-time
Land Surface Temperature,2001-02 (in °C)
Annual Average Day-time
Land Surface Temperature,2018-19 (in °C)
Predicted Annual Average Daytime
Land Surface Temperature,2037-38 (in °C)

Figure 5: Annual Average day-time and Projected LST; Source: Wan, Hook, and Hulley,2015

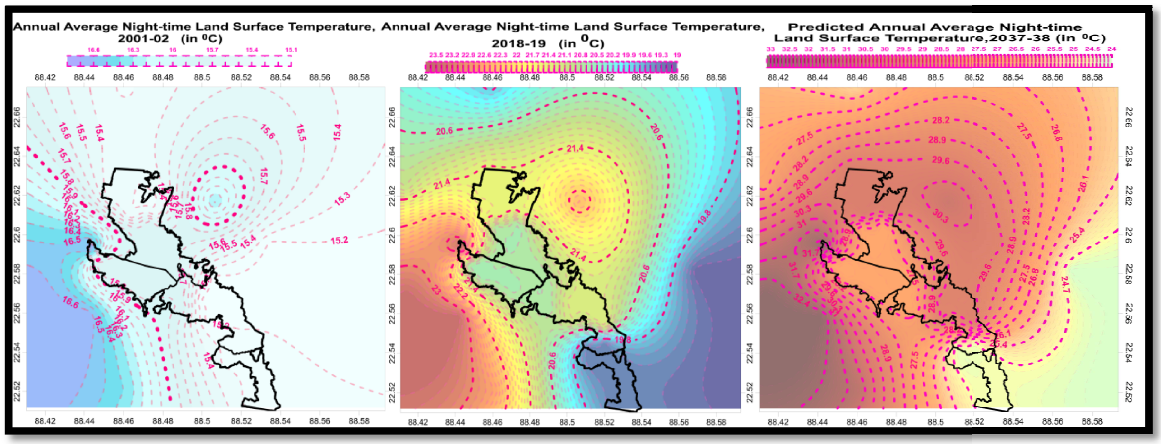
Annual Average Night-time Land Surface Temperature, 2001-02 (in °C)
Annual Average Night-time Land Surface Temperature, 2018-19 (in °C)
Predicted Annual Average Night-time Land Surface Temperature, 2037-38 (in °C)

Figure 6: Annual Average night-time and Projected LST; Source: Wan, Hook, and Hulley, 2015

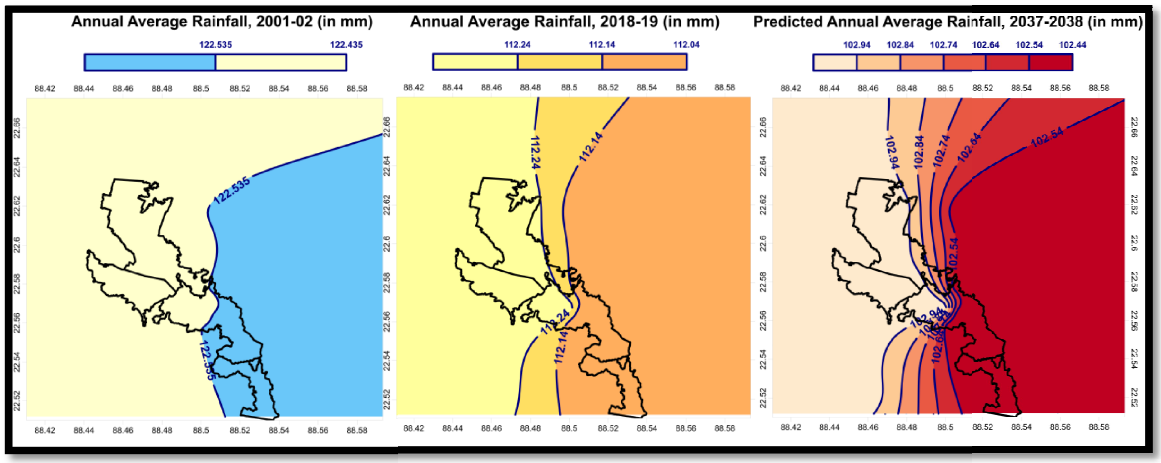
Annual Average Rainfall, 2001-02 (in mm)
Annual Average Rainfall, 2018-19 (in mm)
Predicted Annual Average Rainfall, 2037-2038 (in mm)

Figure 7: Annual average and projected Rainfall estimates in mm per year; Source: TRMM, 2019

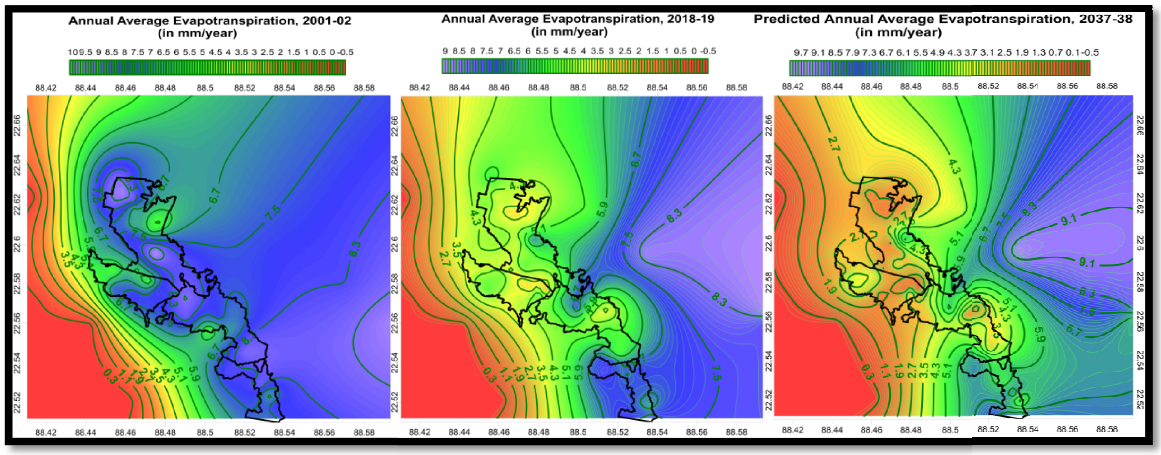
Annual Average Evapotranspiration, 2001-02 (in mm/year)
Annual Average Evapotranspiration, 2018-19 (in mm/year)
Predicted Annual Average Evapotranspiration, 2037-38 (in mm/year)

Figure 8: Annual average and projected Evapo-transpiration estimates in kg/m^2/year or mm/year; Source: Running, Mu, Zhao, 2017.

As evident from Figures 5, 6, 7 and 8, that over the years 2001-02 and 2018-19, both the night time and day time temperatures have soared magnanimously from 18^0 C to around 22^0 C, indicating the effect of the spread of urban attributes. This further suggests the development of localised weather phenomena, as cemented surfaces tend to retain the heat

that they receive during the day. To delve deeper into the hydrological regime of the study area, the extracted annual average rainfall data echoed the findings of the LST images, wherein rainfall decreases from 2001-02 to 2018-19 by almost 10 mm or more at times. With rainfall showing a decrease and LST showing an increase in values, there is bound to be an effect on the Evapotranspiration(ET) values. Converted to kg/m^2/year or in other words mm/year, the ET values have decreased rapidly in urban zones and at places, owing to increasing LST there has been increasing rates of ET. An immediate effect of these varied situations have affected the ground water levels. Wherever there has been less of recharge, more of land temperatures and greater values of ET, groundwater should witness a drop in its piezometric level, coupled by anthropogenic interference. This is evident in the figures which depict annual average rainfall and piezometric level change. Such figures explain the situations existing in 1994-95, 2004-05 and 2016-17. [Since the Central Ground Water Board has not yet published the 2017-18 standards, 2016-17 is the last year for this aspect]. Other than these, to identify how groundwater extraction is adversely affecting the aquifers here, the decadal rise and fall along with the water quality tests with respect to groundwater is an essential proof. With an increasing decadal fall in each of the chosen time-periods, the region witnesses a substantial drop in 2006-07 and 2016-17 which is almost around 3-4 m below ground level on an average. As private complexes and non-gated communities keep on extracting groundwater through bore-wells in bulk, the piezometric level is expected to drop greatly in the future. These parameters have been subjected to multiple regression equations wherein it has been proven that the marginally related parameters during 2001 suddenly become immensely related and highly dependent on one another by 2019. This indicates that instead of the natural processes, intense urbanisation has assumed control over the hydro-geological attributes of the landscape, and as urbanisation progresses the inter-relationship between parameters increase. Notwithstanding this, the NDMI maps represent that over the three chosen years 2001, 2010, and 2019 the amount of area occupied by non-moisture laden soil has increased over the years, depicting the rate of urbanisation, increase in LST rates and as a result greater NDMI values. An additional although marginal factor preventing adequate recharge of the confined aquifer, is the lithology is an additional Action Area I primarily has clayey soil as the topsoil, and as is known, clayey soil does not allow water percolation after a fixed amount of time. So only a total of 3 points is available for marginal recharge but that too will be offset by extraction as huge complexes exist there.

7.2.3.Assessment of the existing water supply system and the cost-effectiveness of the distribution network of New Town(Rajarhat):

7.2.3.1 Methodology:

New Town(Rajarhat)'s administrative authority, the New Town Kolkata Development Authority or NKDA, draws surface water from Rani Debendrabala Ghat in Baghbazar area, over a 20km distance to the 100MGD water treatment plant in New Town(Rajarhat). 10MGD of this water is treated presently. This water is sent through pipelines to the underground reservoirs of gated communities after which the water is pumped to the overhead reservoirs. This is then received by the individual flats. Such an intrinsic supply system is extremely costly considering its growing urban population. Thus to assess the existing water supply system and the cost-effectiveness of the distribution network of New Town(Rajarhat), population growth has been projected till 2025-26 and pitted against the quantity of available tap water supply to find out whether the area already suffers from water stress or not, using the Falkenmark et al. Water Stress Index (2007) equation:

$$WSI = Demand/Supply \quad (6)$$

Following the WSI calculation the following scale would be used wherein looming water scarcity would take place when the values are between $0.2 \leq WSI < 0.4$, whereas actual scarcity and "economically debilitating water stress" scenarios would be characterised by values $WSI \geq 0.4$ and $WSI \geq 0.8$, respectively.

This scenario was projected for the future using a population projection equation as given below:

Projected Population(x) = Present year population*{(1+(r/100)) ^t} (7)

where, r= [{(P2/P1)^(1/t)}-1]*100, P2= Present population, P1= Previous year population; t= interval between censual years,

Projected Water demand (y) = Present year water demand*{(1+(r/100)) ^t} (8)

where, r= [{(P2/P1)^(1/t)}-1]*100; P2= Present year water demand; P1= previous year water demand; t= interval between P2 and P1.

In addition, maps of distribution lines received from the NKDA office were also extensively digitised to pictographically show areas deficient in distribution networks.

7.2.3.2 Results and Discussion:

With respect to the Water supply by the authorities, it is absolutely in a precarious condition. Till date there are many zones in the three Action Areas, where distribution lines have not yet developed(Figure 9).

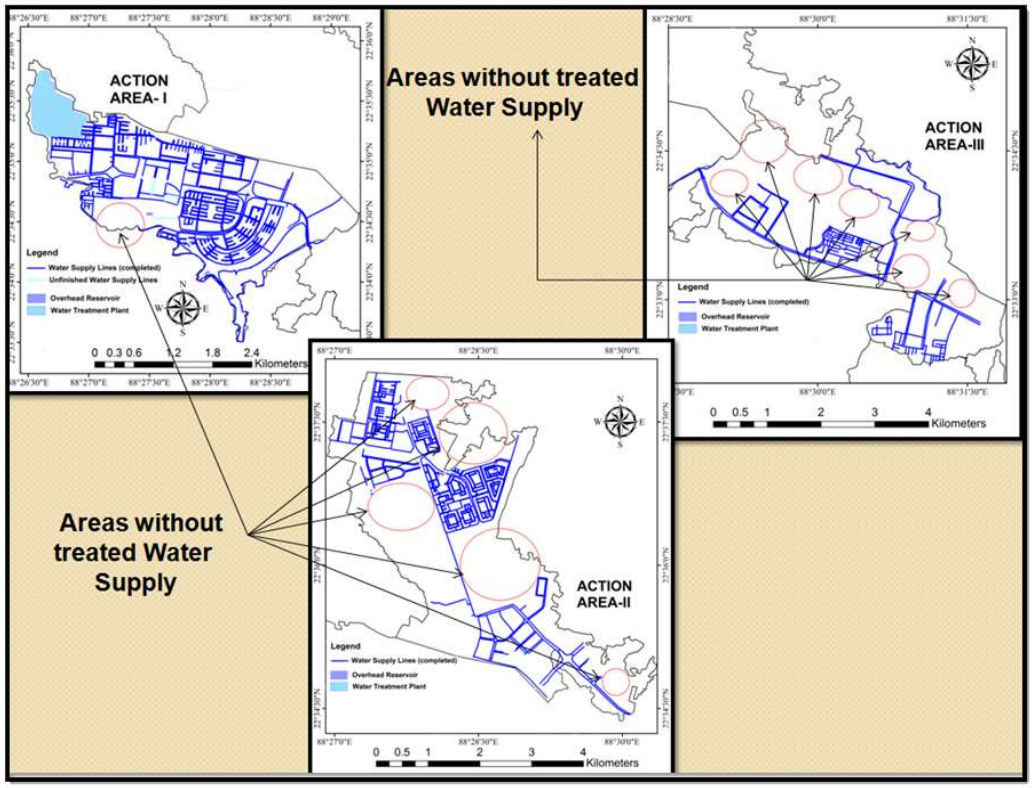

Figure 9: Water Distribution lines within New Town(Rajarhat) and the deficient areas; Source: West Bengal Housing Infrastructure Development Corporation (WBHIDCO)

This is shown by the red circles. This should not happen in those sections which are most developed within the study area. Further due to this situation Bore-well dependency has increased to fill the deficits. Another fact is that not only is there an equitable water provision problem, but there is also a water quality problem. Although the water treatment plant (WTP)claims to purify 10MGD water at the rate of 1 crore rupees a month, the purification somehow gets nullified during its journey to the households leading to bad quality supply water which is unpalatable. So ultimately huge sums of money required to transport the water from the Hooghly to the WTP and from there to the households is all in vain in most cases. The water inspite of being treated at the WTP requires to be purified once again at the homes before it can be ingested, incurring greater monthly expenses Another problem is the feasibility of water provision to a constantly growing population. If the Water Stress situations are seen closely, it is evident that the township as a whole has slumped in Water Stress situations already, given the similar growth pattern of the populace. It is evident from the total population and the WSI compared together, that total population at first increases in Action Area I, followed by Action Area II and III. Even the WSI follows suit. So an alternative to tap and tube-well water is essential.

7.2.4.Assessment of the quality of water used by the households in New Town(Rajarhat) for drinking and other daily requirements:

7.2.4.1 Methodology

Urbanisation has far reaching effects on the water quality of the available water resources. In New Town(Rajarhat), the available water resources are ponds and treated surface water as surface water source and aquifer or tube-well access points as the sub-surface water resource. Although gated communities avail the treated surface water, the remnant villages within the boundaries of New Town(Rajarhat) utilise the water from the aquifers and the ponds for their daily needs. Since all these resources are affected by urbanisation, an assessment of the quality of water used at the households in New Town for drinking and other daily requirements was conducted by testing samples of Tap, Tube-well and Pond water in the laboratory, according to the parameters such as pH, Total Dissolved Solids(TDS measured in mg/l), Total Hardness (TH measured in mg/l), Conductivity (measured in µS), Turbidity(measured in NTU), Salinity, Chlorides, Iron, Sodium, Potassium, Residual Chlorine, Nitrates (all measured in mg/l). For Pond water instead of Iron, Dissolved oxygen (DO) and the BOD parameter have been tested also. These samples were collected during the months of November-December 2018. All parameters except total hardness, residual chlorine and chlorides have been tested using digital meters such as the Systronics Water Analyser 371 and single parametric meters from HORIBA LAQUAtwin series. The rest of the parameters have been tested using the titration procedure. Each of the parameters have limits prescribed by the Bureau of Indian Standards(BIS) for drinking water, and these measured values and the limits have been subjected to Horton's (1965) Water Quality Index (WQI) equations and subsequently maps pertaining to it have been created using the Arc GIS version 10.2.2. The WQI is calculated by using the expression given in Equation (9).

$$WQI = qn\ Wn / Wn \qquad (9)$$

where qn = Quality rating of n th water quality parameter. Wn= Unit weight of n th water quality parameter. Following this calculation, to indicate whether the WQI deems it fit for drinking Yogendra and Puttaiah's (2008) scale has been used where the ranges of WQI, and

their corresponding status of water quality along with their possible use are summarized in the table below:

Table1: WQI and corresponding water quality status

Sl.No	WQI	Status	Possible usages
1	0 – 25	Excellent	Drinking, Irrigation and Industrial
2	26 – 50	Good	Domestic, Irrigation and Industrial
3	51 -75	Fair	Irrigation and Industrial
4	76 – 100	Poor	Irrigation
5	101 -150	Very Poor	Restricted use for Irrigation
6	Above 150	Unfit for Drinking	Proper treatment required before use

7.2.4.2 Results and Discussion

The water samples were collected from each available fresh water source within the study area. 35 tube-well samples were collected. The parameters that were tested depict that each of them have crossed the limits making them unpalatable without extra purification, which has resulted in such high WQI values. Yet these are used for drinking, cooking, washing of utensils, bathing and many more purposes making the people vulnerable to diseases. According to these values, it may be inferred that in areas where the groundwater level has fallen, has the worst groundwater quality and vice versa. 44 Tap water samples were collected and most of them have high TDS, chlorides and total hardness values followed by comparatively high levels of Iron in the tested waters. Except 8 samples which are suitable only for domestic uses other than drinking, all other samples are not even suitable for domestic use without prior purification. The 22 pond water samples within the region have extremely high turbidity, hardness, chlorides, TDS, low DO levels primarily due to the purposes to which the waters are put into, such as washing of clothes, dishwashing, bathing, disposing of idols and associated waste materials during festivities. Many even use it for cooking, as a result indirect ingestion takes place. Since all samples with WQI values greater than 50 are unfit for drinking, it is seen that most people buy water or invest in aquaguards, RO purifiers etc. Hence it may be inferred that in spite of being treated thoroughly at the treatment plant the water is not suitable for direct ingestion and people need to purify the water again.

Following this the Principal component analysis to which the parametric data has been subjected states that it is the TDS, Total hardness, Turbidity, Iron and chloride values for the tube-well samples, sodium, chlorides, TDS and hardness for the Tap water samples and TDS, Hardness, Turbidity parameters being the prime factor affecting the WQI values of pond water source.

7.2.5. Evaluation of the water supply scenario using the perspective of citizens :

7.2.5.1 Methodology:

To understand the perception regarding the available water resources at the consumers end, questionnaire schedules have been used where face to face interviews of individuals were be conducted, using the networked sampling procedure. Questions were framed to trace the individuals age, gender, family size, occupation, income categories, and grey water consumption. Following this, preferences of individuals regarding the bottlenecks in equitable distribution, grievances regarding the available water quality, support for alternative measures, and the need for people inclusive conservation strategies. The scale chosen for this study is a 1 to 5 rating scale, wherein 1 denotes Strongly Disagree and 5 denotes Strongly agree to a particular question. These questions have been asked to both the gated and non-gated people so as to envisage whether at all there exists any contradictions regarding the water supply scenario and water governance within the region.

Response grades given by people were then subjected to the Ridit Analyses, Kruskal Wallis, and Heat mapping technique, so as to depict which components affect the response of the residents for a particular issue, within the ambit of water supply from the available resources.

7.2.5.2 Results and Discussion:

The perspective study has been conducted for 465 household samples within the gated communities and 100 for the non-gated ones. Accordingly, two separated perspectives stand out. Firstly, amongst the non-gated communities the groups who were available for survey primarily came from the less than 10,000 rupees monthly income group or 10-30,000 monthly income group. These households which were surveyed have a family size of around 4 or 7 people although one has a family size of 16 people. Most of these households utilise the groundwater through submersibles and buy water from private water sellers making their monthly water expenses much more than 200 rupees in most cases. Primarily these citizens who need around 10-20 litres of water daily either boil water, use filters or buy water from private sellers. The next majority of people depend on tube-wells and ponds for their daily water needs, and neither of the surveyed households have considered the waters to be fit for drinking. Since they do not receive treated water from NKDA/WBHIDCO they do not pay water taxes but it is the higher income groups who consume the greatest amount of water and agree to pay to get better quality of water instead of investing in expensive water supplies from private enterprises, while the rest do not. Similarly, the responses recorded for questions regarding the bottlenecks in equitable distribution of water state that the non-gated communities believe that the primary hurdle to equal distribution of water is the dearth in the adequate amount of water supplying infrastructure, due to which these individuals cannot use treated water and have to depend on distant water resources for sufficing their water needs. As per the Ridit analysis, the people's primary grievances against the water quality is the increasing monthly expenses for potable water. They further believe that surface water depletion at the expense of urbanisation should not happen as ponds are a source of livelihood and need to be preserved. Further they believe that for them rooftop rainwater harvesting is the only viable way to sustainably use the rainwater and prevent use of more blue-water to control excessive consumption of water, this is followed by support for the recycled water or grey-water supply to households such that a water policy to reduce and re-use available water resources to prevent wastage.

On the other hand, the groups amongst the gated communitieswho were available for questioning came from the 10,000-30,000,30-60,000 and greater than 60,000 rupees monthly income group. These households which were surveyed have a family size of around 3, 4 or 5 people. Most of these households receive treated water from NKDA/WBHIDCO although a large number draws water out from emergency bore-wells, while the rest buys water in spite of receiving treated supply water from the authorities. Few complexes even depend on only groundwater and private water suppliers to meet their water demands. As a result when people need around 6-10 litres of drinking water daily, monthly water expenses for both purifying water at the households and buying water incurs monthly expenses of more than 200 to almost 1000 rupees at times in many cases. The surveyed households who derive water from various sources, have considered the waters to be mostly of an average or bad quality, making it unfit for drinking in most cases for drinking. In spite of receiving treated water from NKDA/WBHIDCO and paying water taxes, the people of all the income groups have to purify water doubly using aquaguards, RO plants within complexes or buy water to meet daily needs. Similar to the previous situation the highest income groups living in the High income group housing (HIG) complexes who consume the greatest amount of water, pay the highest amount of taxes, and yet do not get better quality of water. Yet to get better water quality most people are even willing to pay a bit more if water from taps may be directly ingested. The rest do not want to pay any more simply because they believe this situation is not feasible. Similarly, the responses recorded for questions regarding the bottlenecks in equitable distribution of water, declares that the gated communities believe that the primary hurdle to equal distribution of water is the dearth in the level of awareness amongst people regarding judicious use of water resources, due to which these individuals tend to misuse and waste water. As per the Ridit analysis, the people's primary grievances against the water quality is the increasing deteriorated water quality discolouring the floors. They further believe that with time there will be more water infrastructure created, and this would spearhead the enhancement of water infrastructure facilities. So in the meanwhile the citizens also believe that alternative resource creation and emphasis on them should be increased to sustain the water demands of citizens. Further, they believe that rooftop rainwater harvesting followed by the supply of recycled grey-water to the citizens are the two viable alternatives to sustainably use water and at the same time conserve the blue-water. Thus a uniform water policy can be implemented to reduce and re-use available water resources to prevent wastage.

So implementing water metering, water ATMS, new-age water conservation technologies, repairing the old infrastructures and stabilising water consumption rates are some of the changes which according to the people's wishes would help to reduce the water use rates.

7.2.6. Measures for the sustainable use of water resources within New Town(Rajarhat):

To make the growing township use water more responsibly, certain measures, infrastructural changes need to be implemented. For this purpose, the 3Rs of sustainable development need to be effected. Firstly, although water taxes have been implemented to reduce water consumption and water wastage, proper water meters are essential and rates need to be accorded separately. Following this re-use and recycle is possible within the growing township, through grey water recycling, i.e., treatment of the wash water from basins washing machines, bath tubs etc., may be stored in tanks, and sent back to the apartments for uses which entail gardening, washing of floors, vehicles, compounds etc. The black water or the sewage water is already sent to the 31MLD sewage treatment plant existing within New

Town(Rajarhat), but by creating a centrally located grey water treatment plant the pressure and expenses on all sides might be reduced. Not only will the STP incur lesser costs for treating lesser amount of sewage water, but at the same time the water treatment plant will not have to treat more blue water for the various potable uses of water within the study area, since the water will be treated through an endless loop thereby initiating a largely zero discharge water distribution network.

7.2.6.1 Methodology:

For this purpose, responses of the residents and their grey water footprints have been recorded and a least cost location of setting up a grey water recycling plant have been completed. This has been done in two halves. The first part calculates the perspective grey water footprint from all the domestic households. Following this, points are chosen within the map of New Town(Rajarhat) which mark the centroid of each of the Action Areas. Using the Gravity Potential equation (1) as propounded by Newton, the area with highest attraction/highest grey water footprint was calculated by:

$$\text{Gravity Model } (V_i) = (p1/d_{1j}) + (p2/d_{2j}) + \dots (pi/d_{ij}) \quad (10)$$

where, i= location 1; j= location 2; P1= grey water footprint of location 1; P2= greywater footprint of location 2 and dij= distances between the two places/locations.

The second half comprises of the computation of a similar equation to Grey water Potential. It is called the sphere of influence devised by Reilly to delineate the zone of influence or the total spatial reach of a grey water treatment plant if established in the region of greatest grey water footprint.

$$Bij = Dij/((1+\sqrt{} (Pi/Pj)) \quad (11)$$

where, Bij= the break point between i and j; Dij= Distance between i and j; Pi=Proportion of grey water of the locale i; Pj= Proportion of grey water of the locale j. A cost comparison of WTPs, STPs and Grey water treatment plant (GTPs) have also been calculated.

Following this, another untapped resource in this region is the rainwater. Rainwater is received here at the an average annual rate of 126-112 mm per year, yet none of this is used. But before rooftop or any other type of rainwater harvesting is implemented as an alternative resource, it is essential that samples of rainwater are collected and tested according to the same parameters as mentioned before, such that it may indicate its palatability. Similar to rooftop rainwater harvesting, runoff harvesting is extremely lucrative in this region due to the large number of metalled roads which have a considerably large surface area when compared to other localities or cities within the vicinity of the urban zone. To do this, at first all the roads were digitised within New Town, following which a fishnet was used to create a road density map.

Another option in this regard is the collection of water in urban water-bodies. since very few natural water-bodies exist within the study area, recreation of new water-bodies and revitalisation of old ones are essential. To recreate new water-bodies a Shuttle Radar Topographic Mission (SRTM) imagery was used to detect the low lying regions existing within the boundaries of New Town and proficient areas for urban ponds were delineated. Following this, artificial floating islands (AFI/FTW) concept has been drawn to clean and conserve pond waters, through inclusive community stakeholdership.

7.2.6.2 Results and Discussion:

Rainwater Samples collected without filtration have depicted a very low WQI and therefore rainwater harvesting needs to be encouraged. But this water is a seasonal source. To allow water provisions all year round grey water or wash water recycling is essential. That is why the grey water footprint has been calculated from people's perception. With highest grey water generation in Action Area I, it is conducive to locate a grey water recycling plant there. But unfortunately, due to the shape of New Town(Rajarhat), the influence zones (after Reilly) are much smaller than usual. This is because greater the distance lesser is the influence zone and vice versa. But creating a centralised one as suggested here will mean making 2 subsidiary units- channelling the recycled water towards Action Areas II and III and if possible at IV.

Such a GTP will reduce the load of water treatment at both WTPs and STPs and costs of creating GTPs are comparatively much less as given in the table below:

Table 2.	**Water Treatment Plant**	**Sewage Treatment Plant(STP)**	**Grey water Treatment Plant (GTP)**
. 1	1MLD Cost=**0.8** crore rupees (WTP units including settling tank, clariflocculator, filter house, chlorinator, clear water reservoir)	1 MLD STP=**2.48** crore rupees (Screen filtering, Sedimentation, trickling filter, activated sludge process, aeration, chlorination, release)	1MLD grey water treatment plant=**0.02** crore rupees (Collector tank, Pressure filter, chlorinator)
2	(Additional costs of construction of MS header and HDPE laterals cost=70 to 80 lakhs)	(Additional costs of house to house sewage collection and transmittal of the sewage through combination of Man-hole and concrete pipes=85 to 95 lakhs per sq km.)	(Additional costs of construction of MS header and HDPE laterals cost=60 to 70 lakhs)
Total Cost=	1.5 crores	3.33 crores	0.62 crores

Source: The Greywater Guide, 2019; WBHIDCO, 2019.

Rainwater harvesting from rooftops is also a very good way to store water from the large terraces of the gated communities. Similar to the pilot rainwater harvesting schemes installed within Kolkata, an interconnected pipe from each of the towers of high rise apartments may be used to channel of water into 3 or more 3000 litres HDPE tanks after passing it through an inverted sand gravel filter and utilise it for domestic purposes. The runoff harvesting system, wherein rain wash water is collected from the huge length of roads can be an additional help. If Permeable/porous concrete or permeable polymer roads can be added as a layer on the underlying natural roads, it is said to conserve around 880 gallons a minute. This water can be stored in underground storage units made of reinforced concrete. Given a 36m*10m*4m dimension, 1400 m^3 of filtered water may be stored from one unit and, if sold at a meagre price of 1 rupee per litre will help to generate 9.6 crore rupees from 8 such units, built along a single Major Arterial Road(MARs) units. If multiple units of these are build along just the major lines of communication, huge amounts of water can be store, sold, used, etc., and dependence on the WTP will reduce considerably in the future.

The *Floating* treatment *wetlands* (AFI/FTW), made by the villagers using Arum maculatum, Vetiveria zizanioides, Crinum jagus, etc., species of plants may help to not only clean newly created or pre-existing plants at a cost of just Rs. 1500 per sq.m but will also be a source of subsidiary income for the communities residing in this area as a whole.

8. Concluding Remarks

Water conservation is one of important issues of sustainable environmental management (UNESCO, 2016). Being one of the emerging smart cities, New Town(Rajarhat) needs to consider certain facts if a self proficient and well managed supply network needs to be developed. In the present crisis, where water wars are imminent New Town(Rajarhat) luxuriously aims to draw water from the River Hooghly and the deep tubewells to provide free supply of treated water to its residents in Action Areas I, II,III, IV, for which a large Water Treatment Plant has been developed. This is the situation with respect to a meagre occupancy, which in the future is bound to increase along with the demands. Therefore, it will be difficult to meet the water supply costs. Such a situation has already begun, coupled with problems in equity of distribution, water quality, and public health. Thus, this study will try to achieve water self sufficiency and security in New Town(Rajarhat), through adequate management, protection of the most vulnerable water systems is required along with the mitigation of the impacts of water related hazards such as floods and droughts, safeguarding access to water functions and services and managing water resources in an integrated and equitable manner (UNESCO, 2016). Therefore, maintaining the equity in distribution, creating a pocket friendly pro-poor water pricing policy, preventing obstructions in the quantity and quality of supply in a sustainable way, shall be the goal of this research.

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